Assessment of Service Life for Regenerative ECLSS Resin Beds

Dale L. Cloud[1], Maria C. Keilich[2], Peter T. Polis[3], Stephen J. Yanczura[4]
Hamilton Sundstrand Space Systems International, (HSSSI), A UTC Aerospace Systems Company, Windsor Locks, CT, 06096, USA

The International Space Station (ISS) Water Processor Assembly (WPA) and Oxygen Generation Assembly (OGA) manage and process water at various levels of cleanliness for multiple purposes. The effluent of the WPA and the influent of the OGA require water at very high levels of purity. The bulk of the water purification that occurs in both systems is performed by consumable activated carbon and ion exchange resin beds. Replacement beds must be available on orbit in order to continue the ISS critical processes of water purification and oxygen generation. Various hurdles exist in order to ensure viable spare resin beds. These include the characteristics of resin beds such as: storage environment, shelf life requirements, microbial growth, and variations in the levels and species of contaminants the beds are required to remove. Careful consideration has been given to match water models, bed capacities and spares traffic models to ensure that spares are always viable. The results of these studies and considerations, in particular, how shelf life requirements affect resin bed life management, are documented in this paper.

Nomenclature

A/L CLR	=	Air Lock Coolant Loop Remediation
DI	=	De-Ionizing
DIW	=	De-Ionized Water
Regen ECLSS	=	Regenerative Environmental Control and Life Support System
EMU	=	Extravehicular Mobility Unit
EOL	=	End of Life
ISS	=	International Space Station
IX	=	Ion Exchange
LLIL	=	Limited Life Items List
MCV	=	Microbial Check Valve
MF	=	Multi-Filtration
MSFC	=	Marshall Space Flight Center
OGA	=	Oxygen Generation Assembly
ORU	=	Orbital Replacement Unit
R&R	=	Remove and Replace
TIM	=	Technical Interchange Meeting
TOC	=	Total Organic Carbon
WPA	=	Water Processor Assembly

I. Introduction

A Regenerative Environmental Control and Life Support System (Regen ECLSS) that includes the Oxygen Generation Assembly (OGA) and the Water Processor Assembly (WPA) was developed for the International Space Station (ISS) to reduce the logistics burden of supplying potable water and oxygen. The OGA provides the oxygen needed for crew respiration, cabin leakage makeup, and animal respiration. The OGA uses electrolysis to convert water from the WPA into oxygen and hydrogen. The hydrogen is either vented to space vacuum as a waste product or recycled by reaction with waste carbon dioxide to produce water for crew use along with waste methane

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[1] WPA/OGA Project Engineering Manager, UTAS, One Hamilton Road, M/S 1A-2-W66, non-Member
[2] Systems Engineering Manager, UTAS, One Hamilton Road, M/S 1A-2-W66, non-Member
[3] Staff Project Engineer, UTAS, One Hamilton Road, M/S 1A-2-W66, non-Member
[4] Staff Project Engineer, UTAS, One Hamilton Road, M/S 1A-2-W66, non-Member

gas. The WPA processes humidity condensate from astronaut sweat as well as wastewater from on-orbit experiments, crew hygiene and urine distillate into potable (drinkable) water. This potable water is used by the crew and supplied as an input to the OGA. Primary water treatment is provided by particulate filtration, ion exchange, and carbon sorption via packed beds. In addition, a high-temperature catalytic oxidation process removes residual organics and kills microorganisms to meet final potable water quality specifications. Each bed is incorporated into a separate Orbital Replacement Unit (ORU) for ease of replacement. The exception is the OGA Microbial Check Valve (MCV) which is incorporated into a larger Water ORU.

The operating life, shelf life, and hence the service life of OGA & WPA packed resin beds was revisited based on on-orbit performance data and existing and recent ground testing of aged resin. The operating life is the actual number of hours of operation during which an item must perform its specified function. The shelf life begins at the born-on date (the date when the resin bed is packed) and ends when an item is placed into service. The service life of an ORU is the sum of the operating life and shelf life.

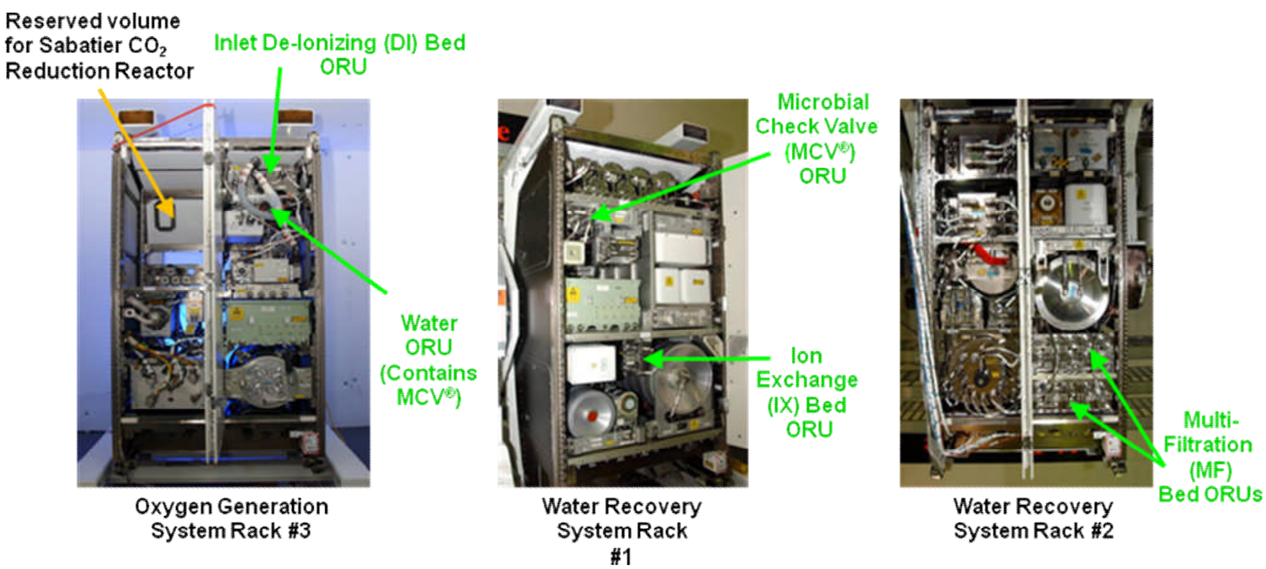

Figure 1. Regen. ECLSS racks. *Location of packed bed ORUs within each rack identified in green.*

II.   Baseline – Water Models and Predicted Throughput

The WPA converts wastewater from hygiene sources, urine distillate, and humidity condensate to potable quality water. The hygiene wastewater is comprised of waste generated from teeth brushing, hand and body wash, and wet shave. Originally the body wash was envisioned as a shower, adding a high soap load to the wastewater. The soaps were eliminated and the body and hand wash were limited to water wipes; thus reducing the primary contaminants in the wastewater to be salts, volatile organic compounds such as ethanol, and microbial species, both bacterial and fungal. Iodine is added to the potable water to maintain sterility. The daily wastewater quantity available for processing was defined as 21.8 kg/day (48 lb/day).

Figure 2 shows a simplified schematic of the WPA. Two identical Multi-Filtration (MF) bed ORUs are located at the front end of the processing section. These beds contain activated charcoal and ion exchange resin to remove the bulk of the organic and inorganic contaminants.   A conductivity sensor at the outlet of the first MF bed ORU is used to indicate when the bed is expended. Once the first bed becomes expended, this bed is removed and the second bed is moved to the first position. A fresh bed is then installed in the second position. A catalytic reactor oxidizes any volatile organics that are not removed in the MF bed ORU. An Ion Exchange (IX) bed ORU at the end of the processing section removes any residual contaminants and provides iodine dosing. A recirculation line also contains an MCV ORU, to act as a microbial barrier between the contaminated wastewater input and the potable product water output.

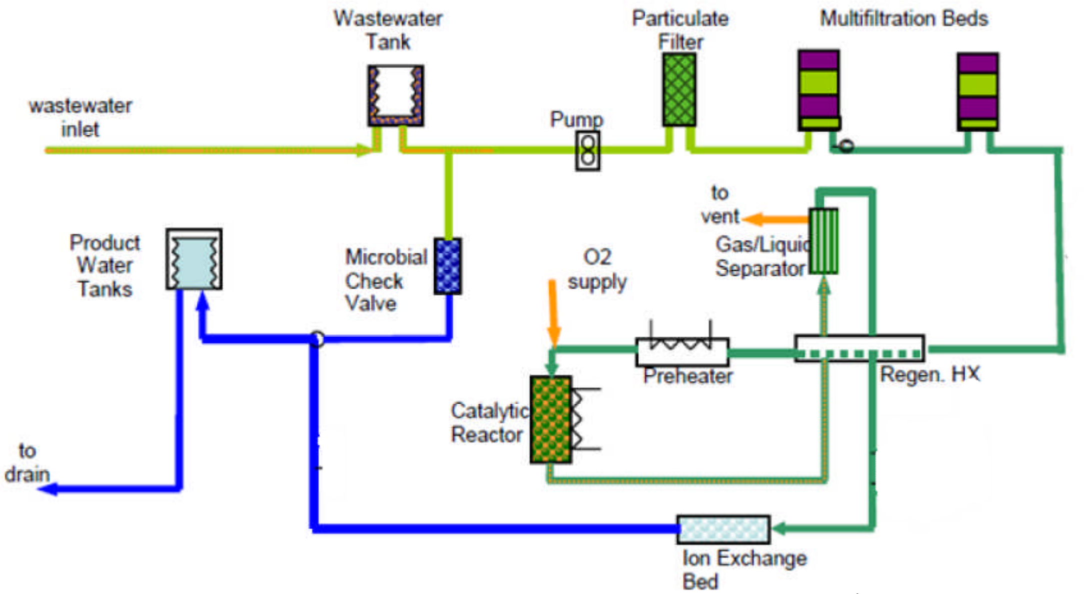

Figure 2. Simplified WPA Schematic[1]

The product water from the WPA is used by the OGA. The water quality requirements for the OGA require removal of iodine from the potable feed water. Figure 3 shows a simplified schematic of the feed water circuit of the OGA. An Inlet De-Ionizing (DI) Bed ORU at the inlet water line to the OGA removes residual contaminants. Any feed water rejected by the OGA is returned to the wastewater bus via an MCV.

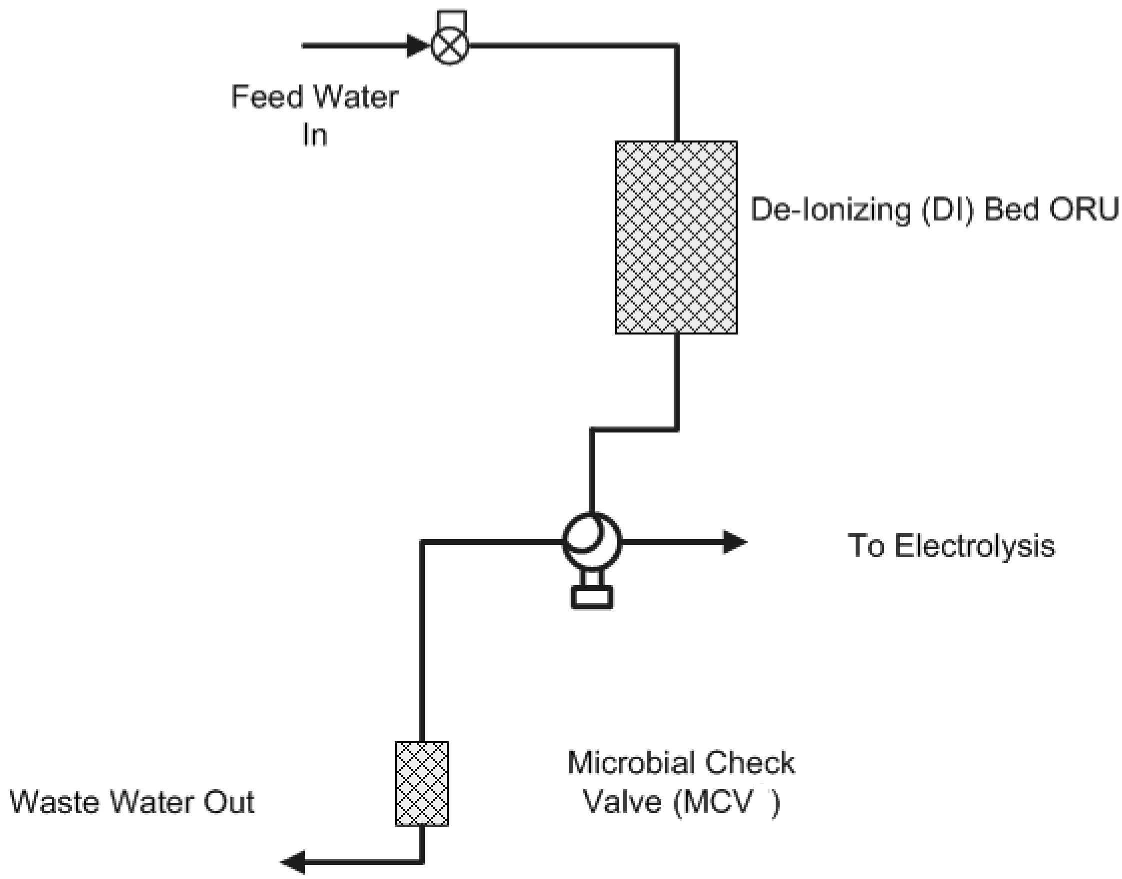

Figure 3. Simplified OGA Feed Water Circuit Schematic

The size of the beds, and therefore life estimates, were driven by throughput and the estimated water model, volume and weight for each resin bed available to each system. Although the WPA and OGA systems were intended to have a ten year operating life, sizing beds for this extended time was prohibitive based on mass and volume budgets. Table 1 summarizes the original shelf and operating life estimates and weights for each of the resin bed ORUs.

Table 1. Baseline shelf and operating life of resin bed ORUs

Item	Operating Life	Shelf Life	Approximate ORU Mass
WPA Multi-Filtration (MF) Bed ORU	150 days	5 years	56.7 kg (125 lbs)
WPA Ion-Exchange (IX) Bed ORU	3 years	5 years	13.2 kg (29 lbs)
WPA Microbial Check Valve (MCV) ORU	1 year	5 years	5.4 kg (12 lbs)
OGA Inlet De-Ionizing (DI) Bed ORU	6 years	5 years	23.6 kg (52 lbs)
OGA Water ORU Contains (MCV)	5 years	5 years	47.6 kg (105 lbs)

III. Resin Bed Technical Interchange Meeting (TIM)

The WPA was brought on line in November 2008, and the OGA was brought on line in January 2009. Water samples from both the inlet wastewater stream into the WPA and the outlet product water stream have revealed a different water composition than originally defined by the water model. Additionally, the water throughput for the systems had also changed significantly from the original estimates. It became necessary to revisit the models used for throughput and water quality and revise them to reflect actual conditions rather than theoretical assumptions. Reacting to these data gathered aboard the ISS had the potential to realize a significant increase in equipment service life. A TIM was conducted in two parts on September 21st, 2012 and October 25th, 2012 to obtain consensus between Boeing, NASA and UTAS on terminology and recommendations for extension of bed life. The resulting changes affected both the service life of resin beds as well as the traffic model used to plan for storing spare hardware quantities onboard ISS.

The following definitions apply to resin beds and by extension the ORUs that contain them:

Shelf Life - "Shelf Life" begins at the born-on-date (the date that the first bed in that ORU has been packed with resin) and continues to the end of life as defined by the Limited Life Item List (LLIL) where, when placed in service, the item will still meet all "Operating Life" requirements.

Operating Life - The actual number of hours of operation during which an item must perform its specified task.

Service Life - The sum of the "Operating Life" and the "Shelf Life". Typically, "Service Life" starts at the start of "Shelf life" and "Service Life" is ended when the item's "Operating Life" is complete.

A. Shelf Life

The expendable beds are comprised of three types of bed media: organic sorbent, ion exchange resin and MCV. With the exception of exposure to contaminants during storage, degradation of charcoal capacity during storage is negligible. Potential degradation of ion exchange resin and MCV capacity determines the allowable shelf life of the Resin Bed ORUs. Industry standards for the shelf life of ion exchange resins are typically listed as two years but this estimate can be extended if the resins are stored properly. Storage guidelines include limiting exposure to oxygen and light as well as limiting long term storage temperatures. For the ion exchange resins, a maximum storage temperature of 48.9°C (120°F) is recommended. For the MCV resin a maximum storage temperature of 26.7°C (80°F) is recommended. Testing at Marshall Space Flight Center (MSFC) was conducted to determine the shelf life of the various beds in the WPA and OGA. In this study the born-on-date was defined as the time of receipt of the packed resin bed instead of the packing date. The age of the resin before receipt at MSFC was not considered.

The test articles for this study were the beds representative of the flight Multi-Filtration (MF) beds. The storage conditions of the study did follow the basic storage guidelines: exposure to oxygen and light was limited since the resins were packed within cylinders and the temperature was maintained at ambient conditions. The results of the study showed no significant performance degradation of any of the various ion exchange and charcoal media after storage for five years. This test did not include the MCV resin but information from Umpqua Research Company (URC), the resin manufacturer, defined a five year shelf life for that resin. A review of the expected exposure temperature showed a range between 1.7°C (35°F) and 42.8°C (109°F) from on ground storage through on orbit usage. The upper limit of 42.8°C (109°F) represents the maximum exposure temperature when installed in the rack although typical rack temperatures range between 21.1°C (70°F) and 26.7°C (80°F). Short term exposure to a maximum temperature of 57.2°C (135°F) is acceptable during on ground shipment. The lower limit of 1.7°C (35°F) represents the on ground refrigeration temperatures of the WPA ORUs. Based upon the MSFC testing and the expected exposure temperatures, the shelf life of each of the ORUs were baselined at five years.

The EMU Air Lock Coolant Loop Remediation (A/L CLR) beds contain ion exchange resins similar to the resins in the WPA and OGA beds. Although the supplier certified a five year shelf life, the need to accurately predict any change in resin capacity over life drove the need to determine the resin degradation rate. Testing in 2008 and subsequently in 2010 on resin stored for two years showed the resin capacity degraded 8% and 12.7% respectively. The previous study at MSFC indicated no degradation in capacity over a five year period of storage. The reason for the discrepancy between the two studies is unclear but may be attributed to the initial age of the resin. Typically the rate of degradation of ion exchange capacity is greatest just after manufacture and decreases as the resin ages. Due to the age of resins used in the MSFC testing, these resins may have already experienced its greatest decrease in capacity before testing began. Based upon this information, an estimate of a constant capacity degradation rate of 6% per year was assumed. This degradation rate is assumed to occur during both the shelf and operational life of the resin.

At the beginning of the TIM, Umpqua Research Company (URC) indicated they had MCV resin that had been stored for twelve years in one of their laboratories. Although the laboratory was not a controlled environment, any excursion above room temperature would potentially degrade the MCV performance and bias any capacity results in a conservative direction. Umpqua Research Company (URC) performed a throughput test on this resin. Figure 4 shows the results of this throughput testing. Also included on this curve are the results of previous testing at Umpqua Research Company (URC) on MCV resin that had been stored for seven and nine years. Although there was no newly manufactured resin to compare to at the time of the testing, the washout curve for the twelve year old resin provided acceptable performance. This testing allowed UTAS to recommend an extension of shelf life to ten years for resins of this family.

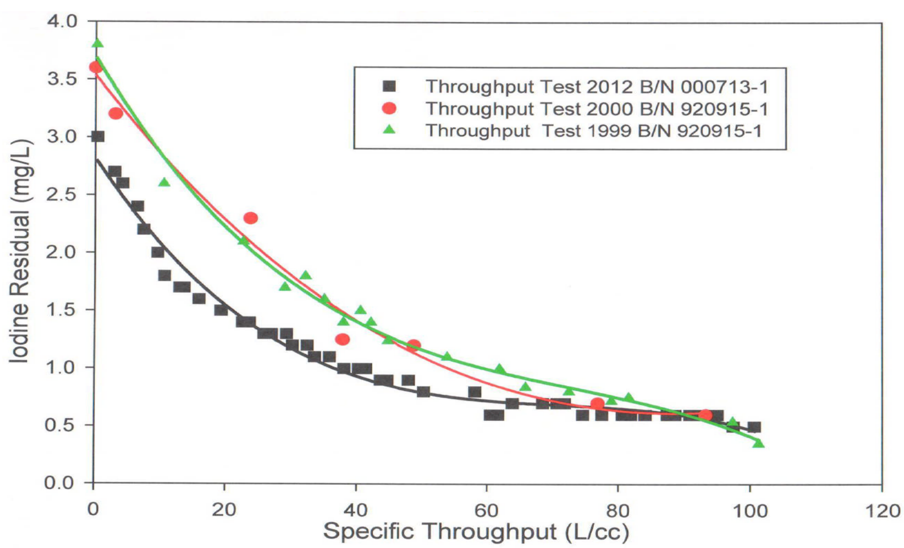

Figure 4. MCV throughput life test @ 21.1°C (70°F). *P/N: MCV-RT 90021-63, B/Ns 000713-1 & 920915-1. Test Dates Nov. 2012, Jan. 1999 & Nov. 2000*

The output from the shelf life discussion was the extension of the shelf life for the MCV beds in the OGA and WPA from five to ten years. The shelf life of the other beds containing ion exchange resin was not extended but a conservative estimate of 6% per year degradation in capacity was assumed.

B. Operating Life

The operating life is determined from both the expected throughput rate and the inlet water model.

Throughput

Previous analyses of the wastewater generation rate for the WPA revealed the daily throughput was approximately 1/4th of the original estimate. The annual production of wastewater has been fairly consistent. For the OGA, the water throughput has varied greatly since the original activation. On orbit data indicate the water throughput was 523.4 kg/year (1,154 lb/yr), 199.6 kg/year (440 lb/yr) and 508.5 kg/year (1,121 lb/yr) for 2009, 2010, and 2011 respectively. At the time of the analysis, the water throughput for 2012 was projected to be 800.1 kg (1,764 lb) for the year. At 800.1 kg/year (1,764 lb/year), the yearly water usage rate is approximately 20% of the original estimate. The throughput of the OGA Water ORU MCV has been at least an order of magnitude less than the original estimate of 232.7 kg/year (513 lbs/year).

Inlet Water Model

Water samples of the WPA wastewater inlet have shown that the wastewater contaminant load is slightly lower than originally estimated although the composition of the contaminants has changed. Due to potential MF and IX bed re-designs, the impact of the changes to the inlet water model was not assessed.

Water samples of the feedwater to the OGA revealed the contaminant load was significantly lower than originally estimated. For the cationic contaminants, the ionic load derived from the on-orbit samples is approximately 1/10th that of the original model. For the anionic contaminants, the ionic load derived from the on orbit samples is approximately 1/3rd that of the original model. In order to account for any future fluctuations in water quality, the impact of this reduced load was not taken into account when re-estimating operating life.

The update to the operating life of the WPA ORUs is being driven by the rate of throughput. The operating life estimates have been increased by a factor of four. For the OGA ORUs, the operating life estimate for the Inlet DI Bed ORU is being driven by the throughput rate and the estimate of a worst case 6% per year degradation of remaining capacity starting when the bed is originally packed. For the present DI Bed installed on orbit at the time of analysis, the water usage rates above were used with the maximum rate of 800.1 kg/year (1,764 lb/year) assumed for future use. Based upon these assumptions, an eight year life is projected with approximately 33% of the capacity remaining. For a new DI Bed ORU the same analysis was conducted except a maximum five year shelf life was assumed and a constant water usage rate of 800.1 kg/year (1,764 lb/year). At the end of eight years, approximately 27% of the original capacity would remain. Therefore, an eight year life can be expected based upon the present operation of the OGA.

For the OGA MCV bed, the inlet water model does not change. The primary function of this MCV bed is to prevent any bacteria in the wastewater from migrating into the OGA feedwater. Even when the MCV is expended and cannot impart the specified level of iodine, sufficient iodine is left on the resin to act as a biocide. A review of the original sizing revealed the bed was sized for a fifteen year life but a conservative value of ten years was used. Since the OGA MCV is an integral part of a larger ORU that has a defined operating life of ten years, the life of the MCV bed was maintained at ten years.

IV. Conclusion

As a result of the TIM, the shelf and operating life of many of the resin bed ORUs has been extended. A summary of the changes can be found in Table 2.

Table 2. Shelf and Operating Life, Pre and Post TIM

Item	Shelf Life Pre TIM	Shelf Life Post TIM	Operating Life Pre TIM	Operating Life Post TIM
WPA Multi-Filtration (MF) Bed ORU	5 years	5 years	150 days	Run to Failure (RTF) [1]
WPA Ion-Exchange (IX) Bed ORU	5 years	[2]	3 years	[2]
WPA Microbial Check Valve (MCV) ORU	5 years	10 years	1 year	4 years
OGA Inlet De-Ionizing (DI) Bed ORU	5 years	[3]	6 years	8 years
OGA Water ORU Contains (MCV)	5 years	10 years	5 years	Shelf + Op. Life = 20 years

[1] – WPA MF Bed ORU remains in system until downstream conductivity sensor detects end of life.
[2] – Service life extension on hold pending WPA MF Bed ORU redesign effort and discussion of Umpqua Research Company's (URC) twelve year old MCV resin testing.
[3] – Shelf life is increased from five years by de-rating the performance of the bed by 6% for each year the ORU exceeds its shelf life.

Due to the extended service lives of the ORUs shown in Table 2, fewer spare ORUs need to be produced and/or refurbished to subsequently be launched. The primary benefit of performing the TIM is therefore realized as a cost savings in production and up/down mass per pound costs. Additionally, crew time required to maintain the OGA and WPA is reduced allowing more time for other activities aboard ISS. The OGA DI Bed ORU was taken as an example to illustrate pre and post TIM traffic models along with corresponding launch costs; this is shown in Figures 5 & 6 and Table 3. While not shown in this paper, the traffic and cost models for all ORUs studied here have moved in a positive direction as a result of the TIM and will save the program significant money and resources as ISS continues to fly through 2028.

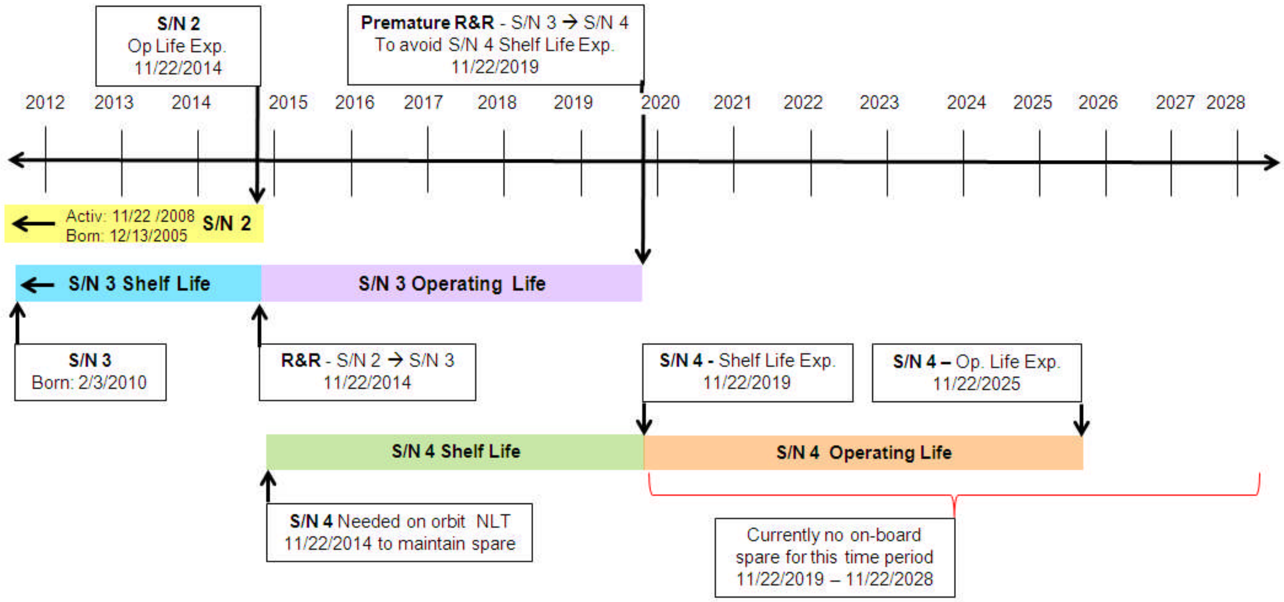

Figure 5. Pre Life TIM Traffic Model for OGA Inlet DI Bed ORU. *This scenario requires multiple new ORU builds and/or used ORU refurbishments (minimum of two) and a minimum of two ORU Remove and Replace (R&R) events (as of this writing) to maintain system operation with one spare ORU on-orbit until 2028.*

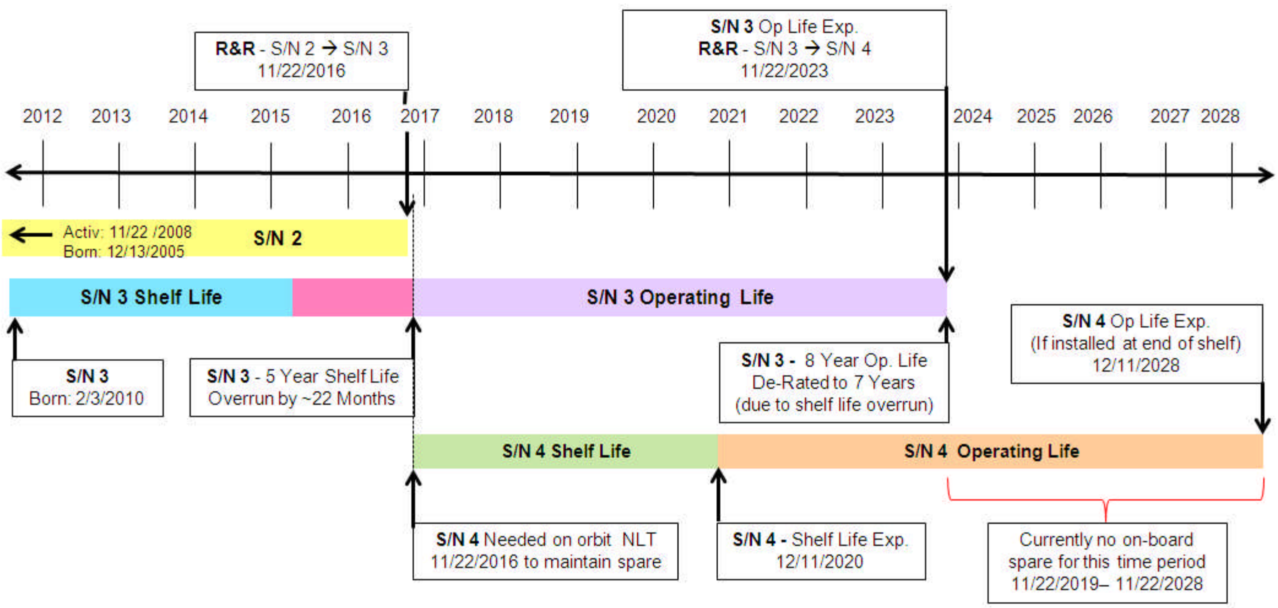

Figure 6. Post Life TIM Traffic Model for OGA Inlet DI Bed ORU. *This scenario requires a minimum of one new ORU build and/or used ORU refurbishment and a minimum of one ORU Remove and Replace (R&R) event (as of this writing) to maintain system operation with one spare ORU on-orbit until 2028.*

Table 3. Launch Cost Savings for an OGA DI Bed ORU due to TIM

PRE TIM	
\$55,085.00 (\$25,000.00)	*\$/kg estimated launch cost* *(\$/lb estimated launch cost)*
2 (minimum)	*ORU launches required*
23.6 (52)	*kg/ORU (lbs/ORU)*
\$2,600,000.00	***Launch cost for DI bed to 2028***
POST TIM	
\$55,085.00 (\$25,000.00)	*\$/kg estimated launch cost* *(\$/lb estimated launch cost)*
1	*ORU launches required*
23.6 (52)	*kg/ORU (lbs/ORU)*
\$1,300,000.00	***Launch cost for DI bed to 2028***
\$1,300,000.00	**Minimum Launch Cost Savings**

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